

Juvenile Salmon in Puget Sound and the Strait of Georgia

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Abstract

Puget Sound and the Strait of Georgia are contiguous inland basins, separated by a number of variable size islands. Both basins are fed by freshwater systems, and are connected to the open ocean via the Strait of Juan de Fuca. Juvenile salmonids (*Oncorhynchus spp.*) were captured in Puget Sound and the Strait of Georgia in July and September surveys from 1997-2002. Survey design and effort were consistent in the Strait of Georgia, but Puget Sound surveys were more variable in both design and effort. Coded wire tags (CWTs) of both coho (*O. kisutch*) and chinook (*O. tshawytscha*) salmon indicate that only a small percentage of juveniles from Puget Sound enter the Strait of Georgia, and these are primarily from fish released in the north-eastern region of the sound. Conversely, no juvenile coho or chinook of British Columbia origin were caught in Puget Sound over the 7 years of study.

In July surveys, standardised catch per unit effort (CPUE) for coho (*O. kisutch*) and chinook (*O. tshawytscha*) were consistently higher for Puget Sound than for the Strait of Georgia, and for all but one year for chum salmon (*O. keta*). CPUEs for pink salmon (*O. gorbuscha*), due to their strong odd:even year dominance, were generally 2-fold higher in Puget Sound than in the Strait of Georgia in even years. In September surveys, CPUE for chinook remained higher in Puget Sound, but coho CPUE was lower in Puget Sound than in the Strait of Georgia and was also lower in both regions than observed in July surveys. CPUE for juvenile chum salmon remained high in Puget Sound in September surveys, but only in odd years. In even years, when substantial pink catches were observed, the CPUE for chum was significantly lower.

Fork lengths showed no clear pattern between the two areas for coho or chinook salmon in either July or September surveys. Chum salmon caught in July surveys were consistently and significantly larger in Puget Sound than catches from the Strait of Georgia. This pattern was generally reversed in the September surveys, with chum salmon from the Strait of Georgia larger than those in Puget Sound. There did not appear to be any impact of pink salmon on chum fork lengths. Both CPUE and fork lengths for all species showed clear increases in 2000, following the 1998 regime shift. CPUE and fork lengths were for all species significantly lower in 2002 than in 2000 or 2001, probably due to variability within the current climate regime.

Introduction

Juvenile salmonids of both hatchery and wild origin enter the Strait of Georgia and Puget Sound (Figure 1) every year. While these two bodies of water are similar in many respects, there are significant differences in size (~ 6300 vs. ~2600 sq km, respectively), freshwater inputs (Strait of Georgia dominated by Fraser River), turnover rates, and general structure. As part of a long-term study on the impacts of climate shifts on the survival and distribution of juvenile salmonids on the west coast of Canada, we have conducted surveys in both these regions from 1997 to 2002. These surveys have been used to estimate abundance (Beamish et al 2000a,b), survival (PSARC 2000, 2001), growth (Beamish et al 2001), diet (King and Beamish, 2000) and hatchery/wild interactions (Sweeting and Beamish, 2003). This paper will discuss some of the similarities and differences observed in juvenile salmon catches, standardised catch per unit effort (CPUE) and size between these two adjoining bodies of water. In addition, data obtained from coded wire tags (CWTs) was analyzed to determine migration routes and mixing between the two regions.

Methods

Specifics of the survey design can be found in Beamish et al. (2000a,b). Briefly, fish were captured with a modified mid-water trawl (approximately 15m x 33m, h x w) towed at roughly 5 knots at the surface. The majority of tows were at the surface, but random tows were conducted throughout the surveys at 15 meter increments. All fishing reported in this paper was conducted between 0630 and 1800, or in daylight hours. The survey design for the Strait of Georgia component of the study has been fixed since 1997 and averages 85 sets per survey (Table 1). The Puget Sound surveys are considerably smaller in scope, and are limited in space by traffic and narrowness of the sound in most areas. Upon completion of a set, the fish were retrieved, sorted by species, counted, and fork lengths (to the nearest mm) were recorded. The sets in the Strait of Georgia are 30 minutes in duration (with the exception of July 1997, when some one hour sets were conducted), whereas space and catch limits in Puget Sound have restricted sets to 15-20 minutes in most cases. The catch per unit effort (CPUE) has been standardized for all sets to one hour. Juvenile sockeye salmon are not captured in sufficient numbers in Puget Sound to make any meaningful comparisons, and are not reported here.



Figure 1. General survey areas of the Strait of Georgia, Puget Sound and Strait of Juan de Fuca. Asterisks denote location of Big Qualicum Hatchery and Chilliwack River Hatchery in British Columbia.

Table 1. Survey effort (number of sets) for surveys conducted in Strait of Georgia and Puget Sound for July and September, 1997-2002. Most sets in Georgia Strait were 30 minutes in duration, whereas most in Puget Sound were 15-20 minutes.

JULY	1997	1998	1999	2000	2001	2002
Strait of Georgia	69	95	98	102	89	101
Puget Sound	14	10	8	3	9	13
SEPTEMBER						
Strait of Georgia	128	95	85	91	102	78
Puget Sound	12	9	8	15	17	16

All coho and chinook salmon captured were scanned for the presence of coded wire tags (CWTs), using a hand-held CWT detector (Northwest Marine Technology, Wash., USA). Data pertaining to the CWTs were obtained from regional mark database (Kuhn 1988) from either Fisheries and Oceans Canada (Strait of Georgia catches) or the Washington Department of Fisheries and Wildlife (Puget Sound catches).

Statistics

Comparisons between corresponding Strait of Georgia and Puget Sound surveys were conducted using either Student T-tests or, in the case of non-parametric data, Mann-Whitney U test, with significance accepted at the $P = 0.05$ level. All statistical tests were performed using INSTAT.

Results

CPUE for coho, chinook, chum and pink salmon are shown for July surveys in Table 2. For coho and chinook salmon, the CPUEs were higher in Puget Sound than in the Strait of Georgia for all years surveyed (1997-2002). With the exception of July of 2000, the same pattern was observed for chum salmon. As noted in Table 1, the survey in Puget Sound was limited to 3 sets in this year. Because pink salmon along the west coast of North America (with the exception of Alaska) exhibit a strong odd year cycle, catches of juveniles are extremely cyclic as well, with almost no catch at all in off years. While CPUEs are much more similar between the Strait of Georgia and Puget Sound for pink salmon, they do show similar trends to the other salmon species. For coho, chinook and chum salmon, CPUEs in the Strait of Georgia increased substantially in 2000 and 2001 from levels obtained in 1997-99. This result was not observed as clearly in Puget Sound. In 2002, catches of these three species declined to pre-2000 levels in the Strait of Georgia. These increases in CPUE in 2000 and 2001 were not observed readily in the Puget Sound surveys, nor was the decline in 2002. Because of the strong cyclical pattern of pink salmon, patterns across years were difficult to ascertain.

Table 2. Catch per unit effort (CPUE) data for juvenile coho, chinook, chum and pink salmon captured in the Strait of Georgia or in Puget Sound in July, 1997-2002.

COHO	1997	1998	1999	2000	2001	2002
Strait of Georgia	13.6	27.1	33.8	98.0	99.0	37.2
Puget Sound	248.2	84.2	452.1	357.0	158.0	364.9
CHINOOK						
Strait of Georgia	41.7	40.2	34.7	75.5	57.9	39.1
Puget Sound	467.0	139.4	616.3	375.0	234.9	474.7
CHUM						
Strait of Georgia	23.8	109.2	84.2	285.5	154.4	21.8
Puget Sound	155.6	168.0	185.6	75.0	200.7	198.0
PINK						
Strait of Georgia	0.5	46.8	0.3	68.6	0.8	53.3
Puget Sound	0.6	78.2	0.0	86.0	0.8	176.4

The CPUEs for chinook salmon in the September surveys (Table 3) show similar patterns as observed in July, although the absolute CPUEs were somewhat lower. For coho salmon, the pattern was actually reversed, with CPUEs now higher in the Strait of Georgia than in Puget Sound. Note that while CPUEs for Puget Sound have decreased dramatically from July levels, those for the Strait of Georgia generally increased for 1997-1999, and decreased by approximately 50% from July values in 2000-2002. Chum salmon demonstrated yet a different pattern than chinook or coho. CPUEs in the Strait of Georgia remained lower than in Puget Sound for 1997, 1999 and for 2001. Note that during these years, the Strait of Georgia CPUEs for chum remained similar to those observed in the July surveys, whereas CPUEs in Puget Sound increased substantially over the corresponding July values. Of particular interest, however, is the chum CPUE pattern exhibited in 1998, 2000 and 2002. In these years, the CPUE for chum were much lower in the September surveys, and were similar to Strait of Georgia levels. The CPUE for these September surveys were also lower than the corresponding July surveys. This result appears to be coincident with the presence of juvenile pink salmon in Puget Sound for these years. This impact was not observed in the July surveys, nor was it seen in the Strait of Georgia in either July or September surveys.

Table 3. Catch per unit effort (CPUE) data for juvenile coho, chinook, chum and pink salmon captured in the Strait of Georgia or in Puget Sound in September, 1997-2002.

COHO	1997	1998	1999	2000	2001	2002
Strait of Georgia	30.4	31.9	48.0	29.5	40.0	16.7
Puget Sound	10.2	7.8	41.8	7.0	11.7	4.5
CHINOOK						
Strait of Georgia	52.8	36.3	29.9	24.2	22.5	37.3
Puget Sound	239.6	119.8	331.0	142.0	125.2	92.8
CHUM						
Strait of Georgia	70.8	79.4	77.4	81.4	77.2	23.7
Puget Sound	454.7	85.6	236.3	91.2	224.1	20.6
PINK						
Strait of Georgia	1.4	57.5	0.2	20.2	1.0	50.0
Puget Sound	0.0	157.3	0.0	503.5	2.0	24.8

Fork lengths (mm) for juvenile coho, chinook and chum salmon from the July and September surveys are shown in Tables 4 and 5. Because the dominance cycle of pink salmon limits meaningful size data to only even years, they are not included in this report. Unlike the CPUE data, there were no clear patterns in size of juvenile coho or chinook salmon between Puget Sound and the Strait of Georgia. Juvenile chum salmon, however, were consistently and significantly larger in Puget Sound than in the Strait of Georgia in all July surveys. This pattern was reversed in September surveys (except 1998), with Puget Sound chum having lower average fork lengths than Strait of Georgia chum. There did not appear to be any influence of juvenile pink salmon on average chum size in 1998, 2000 or 2002 in either July or September.

Table 4. Average fork lengths (FL, in mm) for juvenile coho, chinook and chum salmon captured in the Strait of Georgia or in Puget Sound in July, 1997-2002. Sample sizes are also shown (N). Asterisks denote a significant difference (*, $P < 0.05$; **, $P < 0.01$) between the two areas within a single year. Non-significant differences are denoted by “ns”.

COHO		1997	1998	1999	2000	2001	2002
Str. Georgia	Avg. FL	159.2	172.8	167.6	199.8	185.8	170.3
	(N)	(520)	(1219)	(1646)	(3361)	(3503)	(2184)
		**	**	**	**	**	**
Puget Sound	Avg. FL	208.3	167.4	197.7	193.5	196.7	185.8
	(N)	(849)	(351)	(134)	(198)	(420)	(568)
CHINOOK							
Str. Georgia	Avg. FL	140.3	120.8	139.0	143.7	145.2	139.6
	(N)	(1585)	(1411)	(1664)	(1994)	(2647)	(2411)
		**	ns	**	ns	**	**
Puget Sound	Avg. FL	130.7	124.1	131.4	143.4	127.7	117.6
	(N)	(1405)	(157)	(644)	(289)	(557)	(1089)
CHUM							
Str. Georgia	Avg. FL	121.5	122.3	116.0	127.9	131.3	115.6
	(N)	(899)	(1391)	(1222)	(2607)	(2302)	(1113)
		**	**	**	**	**	**
Puget Sound	Avg. FL	139.1	133.0	139.5	142.7	142.2	121.8
	(N)	(504)	(348)	(325)	(20)	(276)	(333)

Table 5. Average fork lengths (FL, in mm) for juvenile coho, chinook and chum salmon captured in the Strait of Georgia or in Puget Sound in September, 1997-2002. Sample sizes are also shown (N). Asterisks denote a significant difference (*, $P < 0.05$; **, $P < 0.01$) between the two areas within a single year. Non-significant differences are denoted by “ns”.

COHO		1997	1998	1999	2000	2001	2002
Strait of Georgia	Avg. FL	243.4	243.9	229.5	248.0	254.8	245.6
	(N)	(2403)	(1391)	(1602)	(1542)	(1798)	(566)
		*	**	**	ns	**	**
Puget Sound	Avg. FL	249.8	206.9	238.6	253.8	237.4	227.5
	(N)	(51)	(35)	(102)	(51)	(90)	(26)
CHINOOK							
Strait of Georgia	Avg. FL	142.7	169.3	174.0	184.7	188.3	151.7
	(N)	(3655)	(1449)	(1312)	(1440)	(1098)	(1369)
		**	ns	**	**	**	*
Puget Sound	Avg. FL	166.5	166.8	166.4	161.1	152.2	156.6
	(N)	(1046)	(330)	(480)	(838)	(830)	(557)
CHUM							
Strait of Georgia	Avg. FL	191.7	190.3	190.7	202.6	194.5	191.5
	(N)	(2930)	(1876)	(1401)	(2273)	(2624)	(809)
		**	**	**	**	**	**
Puget Sound	Avg. FL	178.7	199.4	172.9	178.1	172.7	161.5
	(N)	(898)	(246)	(203)	(398)	(896)	(117)

The increase in CPUE observed for coho, chinook and chum salmon in the Strait of Georgia in July of 2000 and 2001 was also observed as increased average size of these species. Such size increases were not observed in Puget Sound salmon for either July or September. The decrease in CPUE observed in the July 2002 survey was observed as decreases in average length for coho, chinook and chum salmon in the Strait of Georgia. There were also indications of decreased average sizes for Puget Sound salmon in 2002.

Juvenile salmon migrate from Puget Sound or the Strait of Georgia to the west coast in the late summer or fall, probably dependent upon achievement of a minimal species-dependent size (see Beamish and Mahnken 2001). Capture of juvenile coho and chinook salmon with CWTs present can provide not only estimates of average time of departure from these two regions, but also to determine whether juveniles from Puget Sound move into the Strait of Georgia and vice-versa. The data shown in Table 6 demonstrate that while some juvenile coho do move into the Strait of Georgia, these fish are, by and large, from the most northern release areas of Puget Sound (WA01 and WA02, Figure 2). This region is separated from Puget Sound proper by several islands which may limit their movement in any southerly or westerly directions (also seen in Table 6). Conversely, fish from Puget Sound itself (release areas WA03 through WA05) are rarely encountered in the Strait of Georgia but are observed in greater numbers in the Strait of Juan de Fuca. The potential result of these observations are demonstrated in Figure 3, with a significant input of coho (and chinook, data not shown) from the north-eastern regions of Puget Sound, but not much from the other regions. Similar results are observed in the September surveys for both coho and chinook juveniles (data not shown).

Table 6. Occurrence of coded wire tags from Puget Sound and Strait of Georgia in juvenile coho salmon captured in the Strait of Georgia (SoG), Puget Sound (PSnd) or in Juan de Fuca Strait (JdeF) in July, 1997-2001. Data includes both hatchery and wild CWTs.

Capture site	Year	Puget CWTs	WA01	WA02	WA03	WA04	WA05	SoG CWTs
SoG	1997	4	3	0	0	1	0	30
	1998	8	7	1	0	0	0	35
	1999	12	7	4	0	1	0	34
	2000	42	38	2	2	0	0	193
	2001	66	49	12	2	2	1	188
TOTALS		132	104	19	4	4	1	480
	Year	Puget CWTs	WA01	WA02	WA03	WA04	WA05	SoG CWTs
PSnd	1997	70	0	2	27	30	11	0
	1998	10	0	0	4	5	1	0
	1999	10	0	2	2	6	0	0
	2000	0	0	0	0	0	0	0
	2001	76	0	9	20	33	14	0
TOTALS		166	0	13	53	74	26	0
	Year	Puget CWTs	WA01	WA02	WA03	WA04	WA05	SoG CWTs
JdeF	1997	13	0	0	1	6	6	0
	1998	0	0	0	0	0	0	0
	1999	8	1	1	0	4	2	0
	2000	25	0	1	6	8	10	0
	2001	6	0	0	0	2	4	1
TOTALS		52	1	2	7	20	22	1

Discussion

The Strait of Georgia and Puget Sound are contiguous sheltered ‘oceans’, separated only a short distance by islands and currents. Both bodies of water exhibit surface runoff and deep water replacement via the Strait of Juan de Fuca (the movement of water northward from the Strait of Georgia through Johnston Strait is comparatively low). The regional climate and weather patterns are essentially the same in both areas. However, there are interesting differences that appear. The catch per unit effort data, standardized to catch per hour, demonstrates a much higher abundance and/or density of juveniles in Puget Sound than in the Strait of Georgia. Furthermore, there were differences between the July and September data between the two areas. Releases of both hatchery and wild salmon into Puget Sound, which has a considerably smaller volume than does the Strait of Georgia, is consistently higher than releases from British Columbia hatcheries into the Strait of Georgia, particularly for hatchery chum. The climate shift which occurred in 1998 seems to have impacted the biological ecosystem in the Strait of Georgia in 2000, as evidenced by increased survival (CPUE) and growth (fork length) of all species of juvenile salmonids (Beamish et al. 2001). This does not appear to be as obvious in Puget Sound data, although there is some suggestion that increases in CPUE may have occurred in 1999 rather than 2000. The lower overall effort in Puget Sound makes strict comparisons difficult. The Strait of Georgia also exhibited a decrease in both CPUE and growth of juvenile salmonids in 2002, particularly the July survey, which was only present for coho and chum in the September surveys. In Puget Sound in 2002, a decrease was noted for coho, chum and pink salmon but only in the September surveys. Lower fork lengths, however, were observed in July, as in the Strait of Georgia. These results suggest that local climate and ocean conditions impact on juvenile salmon in similar ways between the two regions, but more regional types of oceanographic and climate impacts may affect the Puget Sound ecosystem earlier than in the Strait of Georgia. Such impacts are difficult to compare given some of the major differences in size, freshwater supply and amount of open water.

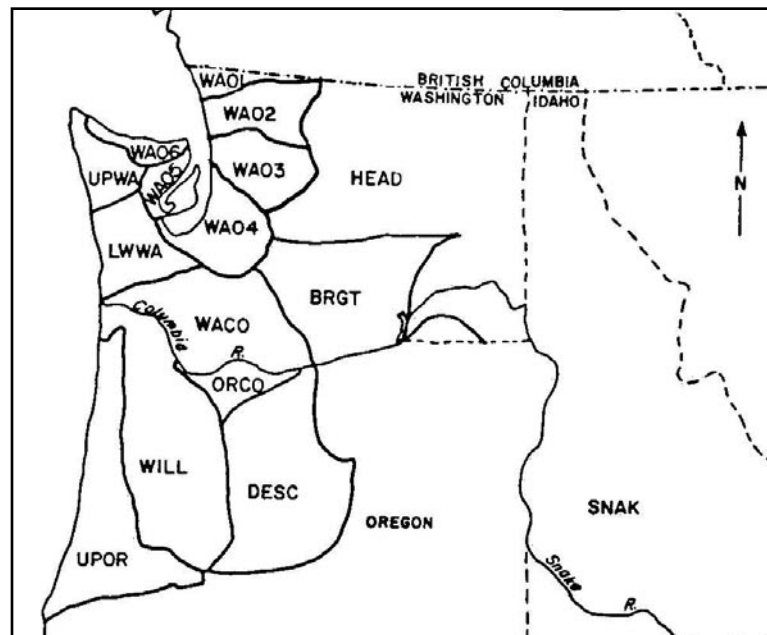


Figure 2. Release areas in Puget Sound and Washington state.

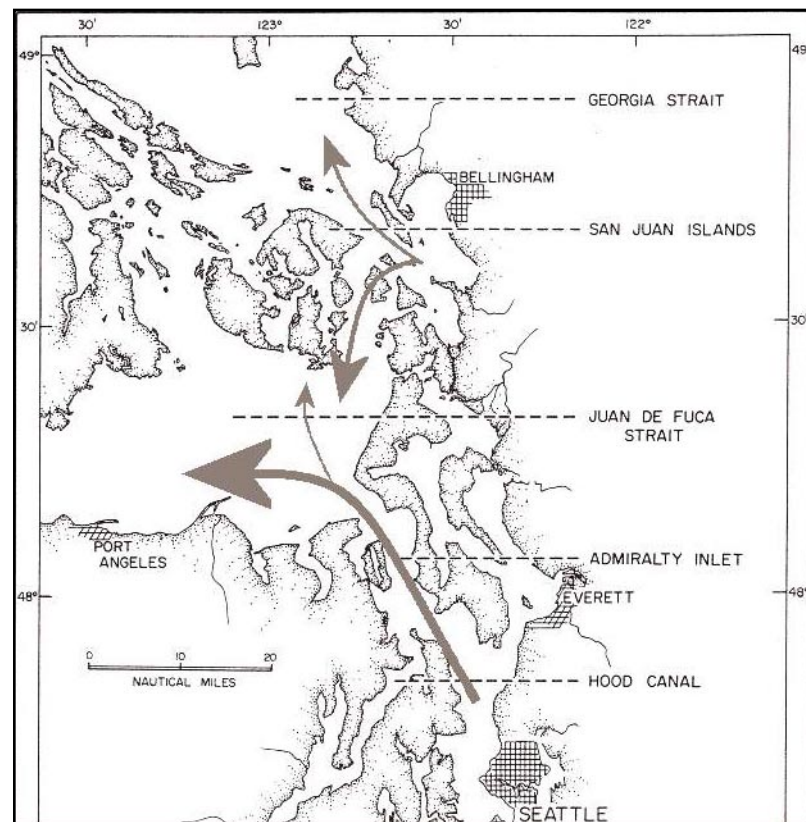


Figure 3. Proposed emigration routes of juvenile coho and chinook salmon from Puget Sound release areas. See text for discussion.

Juvenile coho salmon appear to move out of the Puget Sound region earlier than from the Strait of Georgia, as evidenced by the significantly reduced September CPUEs within Puget Sound, but also by the presence of tagged fish from Puget Sound in Juan de Fuca (and the west coast) in July. Juvenile coho from the Strait of Georgia are rarely found in the Strait of Juan de Fuca in July, and this lack of movement out of the Strait of Georgia was also reflected in relatively equal CPUEs in the two surveys within years.

The fork length data does not exhibit as clear a pattern as did the CPUE or CWT data. Neither coho nor chinook salmon exhibited any consistent pattern between the two regions either within or across years. Juvenile chum salmon were consistently larger in Puget Sound than in the Strait of Georgia in July surveys, but reversed in September. We are not sure of the reasons for this disparity, but the September fork length data suggests that growth of juvenile chum salmon in Puget Sound is not as great as for chum residing in the Strait of Georgia. This idea is supported by the CPUE data, which shows larger catches in September than in July, evidence that chum salmon may not be leaving Puget Sound by this time.

The significantly lower CPUE for juvenile chum salmon in September of those years when juvenile pink salmon were abundant suggests some inter-species density dependency. It is unclear why this impact is not observed in the July surveys, although the CPUE for pink salmon is clearly higher in September than in July in Puget Sound and impacts may be greater at this time than earlier in the year. There is evidence of dietary overlap between juvenile chum and coho salmon (King and Beamish 2000), and such an interaction may explain this result as well (Beamish et al. 2003). More perplexing, however, is the lack of impact on fork lengths for chum salmon in those years when pink salmon are abundant. It would seem logical that an inter-species impact on density would be noted in growth, particularly if dietary overlaps occur. There were insufficient catches of pink salmon in the non-dominant years to determine impacts on pink salmon growth in Puget Sound.

The CWT data suggests a small but relatively stable quantity of Puget Sound juvenile coho salmon enter the Strait of Georgia for utilization as an early marine rearing ground. While not shown, the CWT pattern is essentially identical for juvenile chinook salmon, although the overall numbers of tagged chinook captured in Puget Sound are somewhat greater. In the July and September surveys combined for the entire study period (1997-2001), no CWTs of British Columbia origin were observed for either coho or chinook salmon captured in the Puget Sound sets, indicating that very little movement of juvenile salmon from the Strait of Georgia into Puget Sound occurs. Other studies (this volume) have shown the presence of coho and chinook with CWTs of British Columbia origin captured in Puget Sound, but the numbers are very low. This migration pattern corresponds well with the geography and ocean current models for both the Strait of Georgia and for Puget Sound. In a previous paper by our group (Beamish et al. 2003), we estimated that Puget Sound coho contribute approximately 11% to the overall population of coho in the Strait of Georgia, and this appears to be composed mostly of fish from the WA01 and WA02 regions.

References

- Beamish, R.J., D. McCaughran, J.R. King, R.M. Sweeting, and G.A. McLarlane, 2000a, Estimating the abundance of juvenile coho salmon in the Strait of Georgia by means of surface trawls. *N. Am. J. Fish. Management*, 20:369-375.
- Beamish, R.J., K.L. Poier, R.M. Sweeting and C.M. Neville, 2000b, An abrupt increase in the abundance of juvenile salmon in the Strait of Georgia. NPFAC, Document 473, 18 pp. Fisheries and Oceans Canada, Science Branch - Pacific Region, Pacific Biological Station, Nanaimo, BC, Canada, V9R 5K6.
- Beamish, R.J. and C. Mahnken, 2001, A critical size and period hypothesis to explain natural regulation of salmon abundance and the linkage to climate and climate change. *Prog. Oceanogr.*, 49:423-437.
- Beamish, R.J., C.M. Neville, R.M. Sweeting and K.L. Poier, 2001, Persistence of the improved productivity of 2000 in the Strait of Georgia, British Columbia, Canada, through to 2001. NPAFC Doc. 565. Fisheries and Oceans Canada, Science Branch - Pacific Region, Pacific Biological Station, Nanaimo, BC, Canada, V9R 5K6.
- Beamish, R.J., C.M. Neville, and R.M. Sweeting, 2003, Ecosystem based management should an assessment of Pacific salmon escapement and enhancement on the juvenile salmon that rear in the Strait of Georgia. *Proceedings of the Puget Sound Conference*, this volume.
- King, J.R. and R.J. Beamish, 2000, Diet comparisons indicate a competitive interaction between ocean age-0 chum and coho salmon. *NPAFC, Bulletin* 2:65-74.
- Kuhn, B., 1988, The MRP-reporter program: a data extraction and reporting tool for the mark recovery program database. *Can. Fish. Aquat. Sci. Tech. Rep.*, 1649, 145pp.
- Sweeting, R.M., R.J. Beamish, D.J. Noakes, and C.M. Neville, 2003, Replacement of wild coho salmon by hatchery-reared coho salmon in the Strait of Georgia over the past three decades. *N. Am. J. Fish. Management*, 23:492-502.